Journal of Engineering and Technology
of The Open University of Sri Lanka (JET-OUSL), Vol. 3, No.1, 2015, ISSN 2279-2627

Effect of Structural Parameters on Dimensional Stability and Spirality of Core Spun Cotton/Spandex Single Jersey and 1x1 Rib Structures

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Abstract – *In this research, effect of structural parameters on dimensional stability and spirality variations of core spun CO-SP single jersey and 1x1 rib fabrics made with high, medium and low fabric tightness factors under various relaxation levels have studied and compared the results with the cotton fabrics.*

During relaxation treatments, structural spacing have reduced due to increase of wale and course densities and structural spacing were negatively correlates to fabric tightness factor and relaxation state. Lower structural spacing were reported by cotton-spandex weft knitted fabrics compared to cotton knitted fabrics. Higher stitch densities have given by cotton-spandex structures and it was positively correlated to fabric tightness and relaxation sate. Dimensional constants change with the relaxation level and higher values given by CO-SP structures than CO structures, even though they made with same stitch lengths. CO-SP single jersey and 1x1 rib structures could reach to a stable state faster than CO structures. Significantly lower spirality deformations have given by cotton-spandex fabrics compared to cotton fabrics and thus, 1x1 rib fabrics gave lower spirality angles than single jersey fabrics, even though they made with same fabric tightness. Spirality of deformations weft knitted fabrics were proportionate to TF^{-1} and relaxation level. Hence, mathematical models for spirality variations of cotton-spandex and cotton single jersey and 1x1 rib structures have developed.

Keywords*: Dimensional stability, Spirality, cotton/spandex, structural parameters,*

NOMENCLATURE

CO-SP Cotton-Spandex

CO 100% Cotton

CPC Courses/cm

SKC Structural knit cell

TF Fabric tightness factor

WPC Wales/cm

1 INTRODUCTION

Spirality of knitted fabric takes place when the wales are not perpendicular to the courses, which form an angle between wale direction and vertical direction during manufacturing as well as washing and finishing treatments. It is a very common problem arising with circular knitted fabrics and influences on apparel manufacturing process, aesthetic appearance and functional performances. Most of the problems related to apparel manufacturing occur due to mismatched patterns, sewing difficulties, displacement of side seam of T-shirt and panty hoses to the back and front of the body and garment distortion. Therefore Spirality has been investigated by many researchers from both fundamental and practical aspects.

2 LITERATURE REVIEW

Dimensional stability enables the garments to keep the shape of it during wash and wear and it depends on many factors such as structural parameters, yarn and fabric parameters, relaxation level etc. (Munden, 1960, Herath, 2008 and Marmarali, 2003). Thus, it was reported that tumble drying conditions significantly affected on dimensional stability of weft knitted garments (Higgns *et al.*, 2003). Previous research works clearly demonstrated that the fibre related factors, yarn parameters, fabric and yarn types, knitting machine parameters and knitted structural parameters are the effecting factors for fabric spirality (Araujo and Smith, 1989 and Tao J. *et al.*, 1997). Fabric spirality is significantly affected by the twist of the yarn, which develops torsional stresses due to bending and twisting of yarns. Therefore, stitches have a tendency to rotate inside the fabric to develop spirality (Ceken, 2004, Marmarali, 2003). Thus, it was found that rotor spun and air jet (air vortex) yarns, two plied yarns as well as coarser yarns have shown lesser fabric spirality and thus 50/50 cotton/polyester blends have given a lower tendency to produce spirality in fabrics than the 100% cotton yarns (Deshal, *et al.* 2008). Researchers have experimented the effect of knitting machine parameters such as no. of knitting system used (higher the feeders higher the course inclination), direction of machine rotation, gauge (lower the gauge , lower the spirality) (Ceken and kayacan, 2004 and Deshal, *et. al.* 2008).Knitted structural parameters such as stitch length(higher the stitch length higher the spirality), stitch density (higher the stitch density lower the spirality), fabric tightness factor (higher fabric tightness lower spirality) and relaxation treatments have shown significant influence on fabric spirality [Anad, *et al.* 2002 and Deshal, *et al.* 2008]. Thus, spirality of cotton rib structures have given much lower angles than that of made with single jersey structures [Anad, *et al.* 2002]. However, almost all the research works related to spirality were carried out with cotton and cotton blended fabrics.

3 OBJECTIVES

This research work was carried out to achieve the following objectives.

(a) To study the dimensional stability and spirality variations of core spun CO-SP single jersey and 1x1 rib fabrics made with high, medium and low fabric tightness factors under dry-, wet-, full - relaxation conditions and washing treatments up to 10th washing cycle.

(b) To study the dimensional stability and spirality variations of similar types of CO fabrics made with high, medium and low tightness factors subjected to the same relaxation treatments and laundering treatments and compare the results with the cotton/spandex fabrics.

(c) To analysis to effect of structural parameters on the spirality variations of core spun CO-SP and CO weft knitted fabrics subjected to relaxation and laundering treatments.

4 METHODOLOGY

4.1 Materials

CO-SP (93% cotton and 7% spandex) yarns were used to knit single jersey and 1x1 rib structures in a circular knitting machine. Ring spun 100% cotton (30Ne) and 40decitex "Creora®" spandex filaments (HSSX-40D) from Hyosung Company, South Korea, were used for core spun CO-SP spinning. Thus, for comparing purpose, same structures were knitted using ring spun CO yarns with the nominal count of 30Ne. In order to obtain three tightness factors (TF) of the three structures, three stitch lengths such as low, medium and high were selected. Table 1 shows the knitted yarn specifications. As per the table 1, tenacity of CO-SP yarns are lower, but extension at break and twist are higher than CO yarns. Table 2 shows the knitting specifications. Table 3 gives the machine set stitch lengths and machine off stitch lengths, which were measured under 95% significant level, are given in parenthesis . Machine off stitch lengths of 1x1 rib structures have been calculated according to the SCSL (Structural knit Cell Stitch Length - i.e. length of yarn required to knit one Structural Knit Cell (SKC) concept. Each fabric tightness factor for CO and CO-SP single jersey and 1x1 rib knitted structures were used the same machine set stitch lengths as given in table 3.

Table 1 Specifications of knitted yarns

Material	Nominal count [Ne]	Measured count [tex]	Tenacity [cN/tex]	Extension at break [%]	Yarn twist [tpi]
100%CO	30	20.14	18.217	5.04	19.7
CO/SP	30	20.40	15.245	8.94	27.4

Table 2 Knitting specifications for sample preparation

Structure and Material	Machine diameter [inches]	Gauge	Machine RPM	No. of positive feeders	No. of needles
Single jersey (CO-SP and CO)	30	28	22	72	2640
1x1 Rib (CO-SP and CO)	30	18	20	60	1680

Table 3 Machine set and machine off stitch lengths in cm.

Structure	Material	Low fabric tightness [L-TF] stitch length-cm	Medium fabric tightness [M-TF] stitch length-cm	High fabric tightness [H-TF] stitch length-cm
Single jersey	CO-SP	0.290 (0.268±0.020)	0.270 (0.255±0.012)	0.250 (0.240±0.010)
	CO	0.290 (0.284±0.021)	0.270 (0.262±0.032)	0.250 (0.242±0.041)
1x1 Rib	CO-SP*	0.290 (0.522±0.053)	0.270 (0.488±0.054)	0.250 (0.462±0.066)
	CO*	0.290 (0.586±0.083)	0.270 (0.542±0.051)	0.250 (0.502±0.054)

Note: (1) machine-off stitch lengths given in parenthesis
(2)* machine off stitch lengths measured per SCSL

4.2 Procedure

4.2.1 Sample preparation

Sample size of 30x30 cm^2 were cut from CO and CO-SP knitted fabrics. Six samples were cut from each tightness factor of each knitted structure. All samples were subjected to dry-, wet- and full-relaxation treatments according to the ASTM D 1284-76 standards and then followed by laundering treatments according to the ISO 6330 standards.

4.2.2 Relaxation treatments and laundering treatments

Dry Relaxation

Cut samples were kept for 48 hours on flat surface in a conditioning cabinet with tension free state. Standard atmospheric conditions such as 21°C ± 2 at a relative humidity of 65%±2 were maintained in a conditioning cabinet.

Wet Relaxation

Knitted samples were immersed in a stainless steel water bath containing 0.05g/l standard wetting agent with water temperature, maintaining at about 38 °C and allowed to relax with minimum agitation for 24 hours. Then, samples were hydro-extracted for 1 minute and laid on a flat surface for 48 hours. Then, samples were brought back to the standard condition of 21°C± 2 at a relative humidity of 65% ± 2 for 48 hours with free of tension.

Full Relaxation

Samples were washed thoroughly, briefly hydro extracted for 1 minute and tumble dried for 60 min. and 90 min. durations for single jersey and 1x1 rib knitted structures respectively, around 70 °C. Tumbler dry duration was decided base of on the trial experiments. Samples were then laid on a flat surface in a conditioning cabinet of 21°C±2 at a relative humidity of 65%±2 for 48 hours with free of tension.

Laundering treatments

Full relaxed samples were machine washed up to 10th cycles (washing cycle 1:W1 to washing cycle 10: W10) in a standard front loading machine under normal agitation with machine RPM of 56. Each washing cycle includes wash, rinse, spin and tumble drying steps. After each selected washing cycle, samples were tumble dried around 70°C for 60 minutes and 90 minutes for single jersey and 1x1 rib structures respectively. Washing temperature was set at 40 °C and rinsed with cold water. Thus, water intake for washing was 30 liters. 0.1 g/ *l* standard wetting agent was used. The mass of the load was maintained constant to 3 kg to keep the liquid-material ratio as 1:10.

4.2.3 Measurements

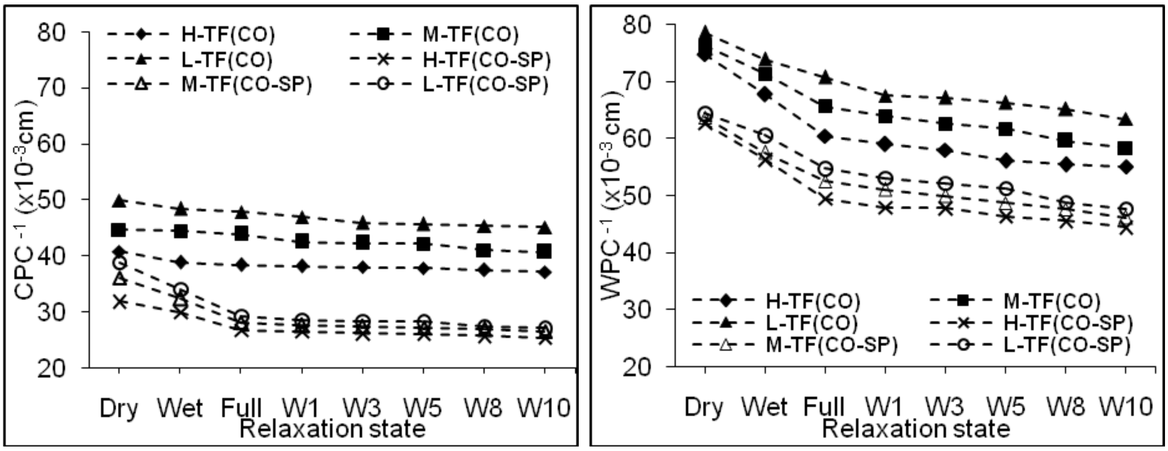
Following measurements have taken after finishing of each relaxation stage and at the end of selected washing treatments such as W1, W3, W5, W8 and W10. Course and wale spacing were calculated based on the measured courses per cm (CPC) and wales per cm(WPC) values as described in the literature (Marmarali, 2003, Araujo and Smith, 1989 and Anad, *et al.* 2002). All CPC and WPC were measured after unraveling the 100 wales or 50 ribs at five places of each sample. Ribs per cm (RPC) of 1x1 rib structures have been measured using SCSL concept. For comparing purposes of structural spacing variations, it was assumed a single rib covered two wales in the 1x1 rib structure. Based on WPC and CPC values, course spacing (CPC^{-1}) and wale spacing (WPC^{-1}) have determined. Spirality angle due to the displacement of wales relative to the courses were measured according to IWS TM 276 standard at the end of each relaxation treatment at five places per each knitted fabric sample.

5 RESULTS AND ANALYSIS

5.1 Structural spacing variations with relaxation

In manufacturing knitted fabrics, yarns are subjected to heavy stress and strains, which will be gradually releasing during relaxation with minimizing the internal energy of structure. This causes to change the stitch shape and therefore, the course density (CPC) and wale density (WPC) can be increased. This will lead to gradually changing the course spacing (CPC^{-1}) and wale (WPC^{-1}) spacing. These structural spacing changes may cause for dimensional instability and spirality in knitted fabrics. Figure 1 and 2 show the changing patterns of structural spacing ($CPC^{-1}$and WPC^{-1}) of CO-SP and CO single jersey structures made with low (L-TF), medium (M-TF) and high (H-TF) tightness factors, under various relaxation stages.

Figure 1 shows that the course and wale spacing have gradually decreased with progressing of relaxation and thus, spacing have drastically reduced from dry relaxation to full relaxation and further reduced with washing treatments. In wet relaxation, water can act as a lubricant to support to change the stitch shape by releasing strains to achieve minimum energy level. Thus, tumble dying in full relaxation further provides the heat energy to reach to the stable states of the stitch shape. In washing, water agitation provide both these facilities to knitted stitches to come to a stable state, meanwhile the course and wale densities increase with decreasing the structural spacing.



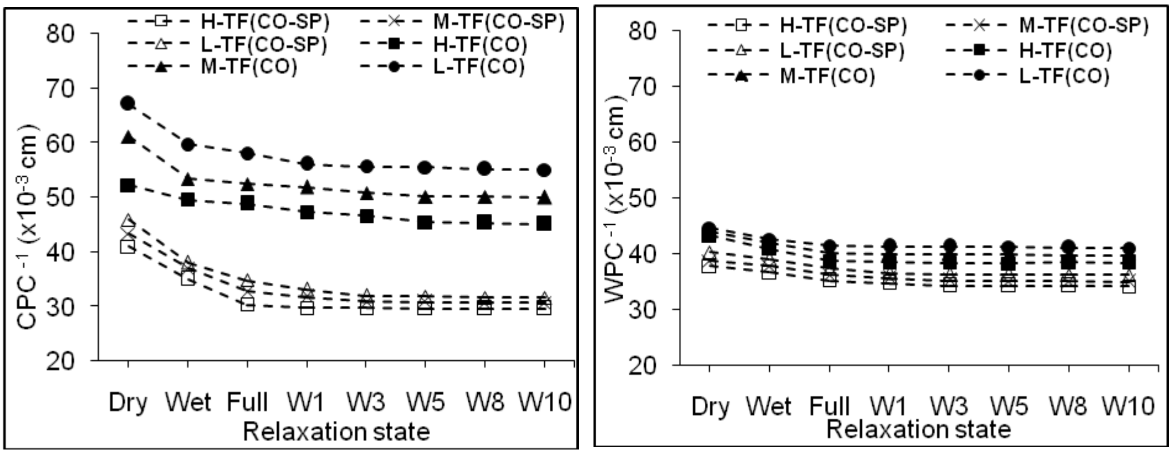
(a) Changes of course spacing (CPC^{-1}) **(b) Change of wale spacing (WPC^{-1})**

Figure 1 Changes of structure spacing of single jersey fabrics under relaxation

According to both figures, it can be observed that lower structural spacing reported by CO-SP structures than CO single jersey structures after all relaxation treatments. Reasons would be that CO-SP single jersey structures gave lower machine off stitch lengths than that of CO structures as shown in Table 3, due to - higher stretch and recovery properties of CO-SP, so CO-SP structures have lower stitch lengths than CO structures resulting higher CPC and WPC, in other wards lower course spacing and lower wale spacing.

In addition to that structural spacing are negatively correlated to the fabric tightness factors in all experimented cases. Reason would be that structural spacing cannot be increased during relaxation the higher fabric tightness structures (having higher stitch densities) due to restrictions imposed by inter yarn friction and compression forces (Higgns *et al.*, 2003, Tao J. *et al.*, 1997). Thus, deviations of course and wale spacing among three fabric tightness factors are higher in CO-SP single jersey structures than CO structures after each relaxation level. A feature observed in figure 1 was the higher wale spacing than course spacing. This is because the lower WPC than CPC in the CO-SP and CO single jersey structures.

Figure 2 shows the structural space changes given by 1x1 rib structures made with CO and CO-SP yarns. They show the same structural spacing changing patterns as single jersey structures such as lower structural spacing given by CO-SP rib structures, negatively correlated structural spacing with fabric tightness factors, drastically reduced structural spacing from dry relaxation to full relaxation, gradually continuing the spacing reduction till 10th washing cycle and clear deviations of course and wale spacing of CO-SP rib fabrics than CO rib fabrics. However, in 1x1 rib CO-SP and CO structures show higher CPC^{-1} than WPC^{-1} due to lower CPC than WPC. This is a conflicting characteristic compared to single jersey structures.



(a) Changes of course spacing (CPC-1) **(b) Change of wale spacing (WPC-1)**

Figure 2 Change of structure spacing of 1x1 rib fabrics under relaxation

5.2 Stitch density variations with relaxation

Due to the decreasing patterns of structural spacing of CO-SP and CO single jersey structures during relaxation, stitch densities of them are increasing. This causes for many structural deformations and spirality is an important one of them. Figure 3 and 4 show the stitch density variations of CO and CO-SP single jersey and 1x1 rib structures under relaxation treatments.

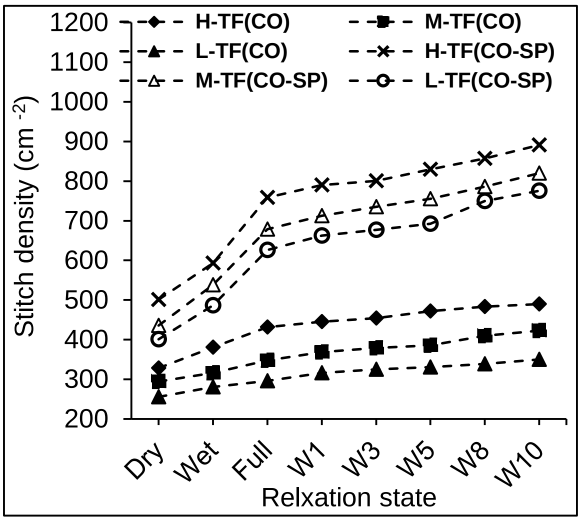


Figure 3 Stitch density variations of single jersey fabrics under relaxation

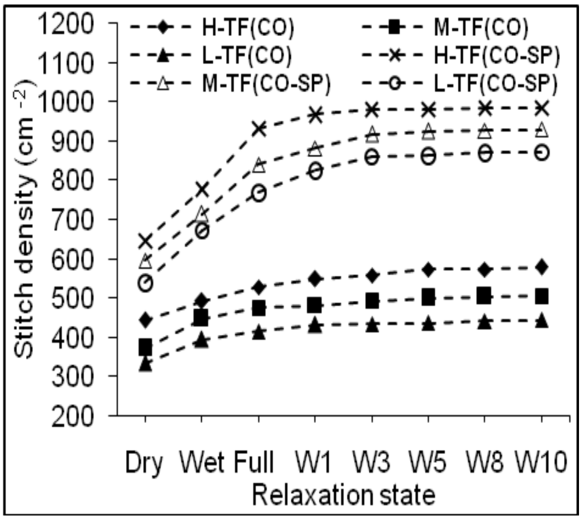


Figure 4 Stitch density variations of 1x1 rib fabrics under relaxation

According to figures 3 and 4, higher stitch densities reported with CO-SP single jersey and 1x1 rib fabrics. This is due to the lower structural spacing reported by CO-SP knitted fabrics due to its good resiliency than CO knitted fabrics at all relaxation levels. Further CO-SP and CO rib fabrics have shown higher stitch densities than the single jersey fabrics, even though their machine set stitch lengths are same for each fabric tightness factor (as given in Table 3). This may be due to the double layer (two planar) construction of rib structures resulting overlapping of wales and increasing the WPC, whereas single jersey is a single layer construction (single planar) and no overlapping of wales. Higher TF means that the particular structure has higher stitch densities. When the stitch densities are higher, wales cannot displace due to higher compression given by neighboring stitches of wales as well as higher inter yarn friction, which can cause to reduce the spirality of knitted fabrics with increasing fabric tightness. Thus, stitch densities have shown progressive increases with relaxation treatments. This is due to changing the shape of the stitch allowing accommodating more no. of stitches per unit fabric area.

5.3 Dimensional stability under relaxation

When the structural spacing and stitch density changes take place in a knitted structure, it effects on the dimensional parameters, which was determined using Munden's geometrical correlations-K values- (Munden,1960) as given below. Dimensional stability is normally expressed by these dimensional parameters. If the dimensional parameters becomes to a stable states, fabric will not have further dimensional deformations (i.e.: Dimensionally stable). Stitch shape factor (Kp) gives the states of changing the shape of the stitch, which is responsible for the dimensional deformations and spirality.

$$\text{Kp} = (\text{courses.cm}^{-1}) / (\text{wales.cm}^{-1}) = \frac{K_C}{K_W} \quad (K_C \, and \, K_W \ \ dimensional\ constants) \qquad (1)$$

Where

$$\text{courses.cm}^{-1}\ (\text{CPC}) = \frac{K_C}{l} \qquad (2)$$

$$\text{Wales.cm}^{-1}\ (\text{WPC}) = \frac{K_W}{l} \ (\ l : stitch\ \ length) \qquad (3)$$

Dimensional constant for stitch density variations (Ks) using following formula.

$$\text{Stitch density (S)} = (\text{courses.cm}^{-1} \text{ x wales.cm}^{-1}) = \frac{K_C \times K_W}{l^2} = \frac{K_S}{l^2} \qquad (4)$$

Table 4 and 5 give the dimensional constants for CO-SP and CO single jersey structures respectively. According to above table, Kp and Ks values have gradually increased with the relaxation level. That means the stitch densities and stitch shapes have changed through the treatments. Further, the cV% of Kp values have calculated to determine the completely relax state (i.e: minimum energy state) of knitted stitches, which can be decided, if the cV% (coefficient of variations) of Kp values are taken lower values.

According to the cV% after W8 and W10, stitch shapes reach to a better stable state and therefore, lesser deformation in the structure can be expected. It means that CO-SP single jersey fabric became dimensionally stable and lower spirality deformations after W8 and W10. According to the table 5, all K values of CO fabrics are lower than that of CO-SP fabrics. It implies that tendency of changing the shape of CO-SP plain stitch is not very fast like in the case of CO-SP structures. Based on the cV% values of Kp, it can be said that the CO single jersey fabric have not reach to a stable state even after W10. Therefore, further dimensional and spirality deformations can be expected with CO knitted fabric structures. However, it was observed from table 4 that CO-SP structures reached to a comparatively better stable state after W8. This is because the higher resiliency characteristics of CO-SP knitted yarns. As a result, higher dimensional stability and lower spirality deformations can be expected from CO-SP single jersey structures.

Table 6 and 7 shows the variations of K-values CO-SP and CO 1x1 rib fabrics. According to them, K values related to CO-SP and CO 1x1 rib fabrics increased with progression of relaxation treatments. The K- values of 1x1 rib structures are higher than the values given by single jersey fabrics. Because, 1x1 rib structures have higher structural parameter values (as resiliency), higher stitch shape changes and higher stitch lengths.

Table 4 Dimensional constants (K-values) for CO-SP single jersey fabrics

TF	Ks	Kc	Kw	Kp	Relaxation state
L-TF	27.47±0.21	6.75±0.05	4.07±0.02	1.66±0.01	Dry relax cV% of K_p=9.67
M-TF	27.49±0.16	6.96±0.03	3.95±0.02	1.76±0.01	
H-TF	28.20±0.23	7.50±0.04	3.76±0.03	2.00±0.02	
L-TF	35.92±0.40	8.00±0.05	4.49±0.03	1.78±0.01	Wet relax cV% of K_p =7.16
M-TF	33.34±0.23	7.79±0.02	4.28±0.02	1.82±0.04	
H-TF	33.84±0.11	7.98±0.02	4.24±0.01	2.03±0.01	
L-TF	42.65±0.35	8.98±0.03	4.75±0.04	1.89±0.02	Full relax cV% of K_p =0.92
M-TF	42.79±022	8.99±0.03	4.76±0.02	1.89±0.01	
H-TF	43.00±0.47	8.94±0.04	4.81±0.05	1.86±0.01	
L-TF	45.73±0.42	9.24±0.02	4.95±0.04	1.86±0.02	W1 cV% of $K_{p=}$ 0.31
M-TF	43.78±0.37	9.01±0.03	4.86±0.04	1.85±0.02	
H-TF	42.76±0.37	8.89±0.04	4.81±0.03	1.85±0.02	
L-TF	45.76±0.55	9.19±0.07	4.98±0.04	1.84±0.02	W3 cV% of K_p=0.54
M-TF	44.01±0.29	9.02±0.03	4.88±0.03	1.85±0.01	
H-TF	43.14±0.38	8.95±0.04	4.82±0.04	1.86±0.02	
L-TF	46.80±0.48	9.25±0.04	5.06±0.04	1.83±0.01	W5 cV% of K_p=0.82
M-TF	44.59±0.28	9.10±0.04	4.90±0.03	1.85±0.02	
H-TF	43.79±0.36	9.02±0.06	4.85±0.05	1.86±0.02	
L-TF	47.05±0.60	9.30±0.02	5.06±0.06	1.84±0.02	W8 cV% of K_p=0.31
M-TF	45.44±0.22	9.12±0.02	4.95±0.02	1.84±0.01	
H-TF	44.11±0.36	9.04±0.03	4.88±0.04	1.85±0.01	
L-TF	47.56±0.41	9.40±0.06	5.06±0.05	1.86±0.01	W10 cV% of K_p=0.30
M-TF	47.13±0.32	9.39±0.02	5.02±0.03	1.87±0.01	
H-TF	44.49±0.35	9.10±0.04	4.89±0.03	1.86±0.01	

Note: all K-values calculated under 95% significant level

Table 5 Dimensional constants values (K-values) for CO single jersey fabrics

TF	Ks	Kc	Kw	Kp	Relaxation state
L-TF	18.95±0.20	5.46±0.02	3.47±0.03	1.57±0.02	Dry relax cV% of K_p=13.62
M-TF	19.19±0.20	5.78±0.04	3.32±0.03	1.74±0.02	
H-TF	21.47±0.21	6.65±0.02	3.23±0.03	2.05±0.02	
L-TF	21.80±0.22	5.65±0.02	3.87±0.03	1.45±0.01	Wet relax cV% of K_p=15.1
M-TF	22.01±0.20	5.99±0.04	3.67±0.02	1.63±0.01	
H-TF	23.32±0.23	6.74±0.03	3.46±0.03	1.95±0.02	
L-TF	23.30±0.25	5.87±0.02	3.97±0.03	1.48±0.02	Full relax cV% of K_p=1.77
M-TF	22.89±0.23	5.82±0.04	3.95±0.02	1.47±0.01	
H-TF	23.28±0.32	5.94±0.04	3.92±0.03	1.52±0.02	
L-TF	24.54±0.22	6.06±0.03	4.05±0.03	1.50±0.01	W1 cV% of Kp=2.35
M-TF	24.60±0.27	6.12±0.02	4.02±0.04	1.52±0.01	
H-TF	25.48±0.20	6.34±0.03	4.02±0.02	1.57±0.01	
L-TF	24.88±0.29	6.10±0.04	4.08±0.03	1.50±0.01	W3 cV% of Kp= 2.47
M-TF	24.98±0.29	6.14±0.04	4.07±0.04	1.51±0.02	
H-TF	25.98±0.19	6.40±0.04	4.06±0.01	1.57±0.01	
L-TF	25.13±0.38	6.13±0.02	4.10±0.04	1.50±0.01	W5 cV% of Kp=2.27
M-TF	25.28±0.26	6.15±0.02	4.11±0.03	1.50±0.01	
H-TF	26.31±0.18	6.42±0.04	4.10±0.04	1.56±0.01	
L-TF	25.35±0.25	6.20±0.04	4.09±0.03	1.52±0.02	W8 cV% of Kp=1.50
M-TF	25.72±0.24	6.28±0.04	4.10±0.02	1.52±0.01	
H-TF	26.35±0.22	6.41±0.03	4.11±0.03	1.56±0.01	
L-TF	25.62±0.32	6.25±0.04	4.10±0.03	1.52±0.02	W10 cV% of Kp=0.99
M-TF	25.76±0.32	6.30±0.03	4.09±0.04	1.54±0.02	
H-TF	26.45±0.25	6.41±0.01	4.12±0.03	1.55±0.01	

Note: all K-values calculated under 95% significant level

According to the cV% of Kp values given in Tables 6 & 7, CO-SP rib structures became to a more reasonable relax/stable state after W10, but CO rib structures need more vigorous treatments to come to a better stable state. Reason for more stable state of CO-SP 1x1 rib structures would be its' higher resiliency property, which makes higher stitch shape changes and therefore they quickly become to a minimum energy levels. Then, there is no potential energy for further changes. This helps to make a quick equilibrium between knitted stitch relaxation and consolidation mechanisms. Therefore, resiliency property of CO-SP yarns give valuable advantage to the single jersey and 1x1 rib structures to become to a quicker dimensionally stable level and also to have a lesser spirality deformations during relaxation, even though they made with same fabric tightness.

Compared with CO single jersey structures of CO, 1x1 rib CO structures became a poor stable state during our experimental conditions, according to the higher cV% given by single jersey CO than CO rib fabrics. Reasons would be the complexity of rib structure construction such as its double layer construction, which may be possible to release more potential energy to become to a stable state during treatments. Due to the high resiliency power of CO-SP yarns, CO-SP 1x1 rib structures would be able to eliminate these restrictions acting on interlacing points of a knitted stitch. It can be concluded that experimented CO-SP weft knitted structures were dimensionally more stable than the structures made from CO.

Table 6 Dimensional constant values (K-values) for CO-SP 1x1 rib fabrics

TF	Ks	Kc	Kw	Kp	Relaxation level
L-TF	73.49±0.46	11.36±0.06	6.46±0.03	1.76±0.01	Dry relax cV% of Kp= 2.77
M-TF	69.23±0.79	11.02±0.11	6.28±0.03	1.75±0.01	
H-TF	67.17±0.68	11.13±0.05	6.04±0.06	1.84±0.02	
L-TF	88.03±0.57	13.54±0.07	6.49±0.02	2.08±0.01	Wet relax cV% of Kp= 1.28
M-TF	82.41±0.54	12.96±0.08	6.35±0.03	2.04±0.02	
H-TF	77.34±0.78	12.74±0.09	6.07±0.04	2.09±0.02	
L-TF	100.54±0.66	14.68±0.06	6.85±0.02	2.14±0.01	Full relax cV% of Kp= 2.73
M-TF	94.09±0.84	14.41±0.11	6.53±0.01	2.21±0.01	
H-TF	106.15±0.77	15.50±0.06	6.84±0.03	2.26±0.01	
L-TF	106.15±0.77	15.50±0.06	6.84±0.03	2.26±0.01	W1 cV% of Kp=0.68
M-TF	98.67±0.66	14.89±0.07	6.62±0.02	2.24±0.02	
H-TF	93.65±0.69	14.79±0.09	6.33±0.02	2.33±0.01	
L-TF	98.67±0.66	14.89±0.07	6.62±0.02	2.24±0.02	W3 cV% of Kp=0.75
M-TF	93.65±0.69	14.79±0.09	6.33±0.02	2.33±0.01	
H-TF	107.63±0.91	15.70±0.10	6.87±0.04	2.28±0.02	
L-TF	100.93±0.68	15.17±0.07	6.65±0.01	2.28±0.01	W5 cV% of Kp=0.75
M-TF	93.36±0.38	14.69±0.04	6.35±0.01	2.31±0.01	
H-TF	106.68±0.77	15.61±0.08	6.83±0.02	2.28±0.01	
L-TF	99.76±0.67	15.10±0.09	6.61±0.01	2.28±0.01	W8 cV% of Kp= 0.66
M-TF	93.05±0.57	14.66±0.06	6.34±0.03	2.31±0.01	
H-TF	107.03±0.70	15.67±0.06	6.82±0.02	2.29±0.01	
L-TF	99.64±0.64	15.08±0.09	6.61±0.01	2.28±0.01	W10 cV% of Kp= 0.5
M-TF	90.40±0.51	14.46±0.04	6.25±0.02	2.31±0.01	
H-TF	106.86±0.62	15.64±0.05	6.83±0.02	2.28±0.01	

Note: all K-values calculated under 95% significant level

Table 7 Dimensional constant values (K-values) for CO 1x1 rib fabrics

TF	Ks	Kc	Kw	Kp	Relaxation level
L-TF	53.46±0.46	8.33±0.05	6.41±0.03	1.30±0.01	Dry relax cV% of Kp=12.9
M-TF	48.35±0.30	8.30±0.05	5.82±0.02	1.42±0.01	
H-TF	55.16±0.82	9.59±0.09	5.74±0.05	1.67±0.02	
L-TF	56.49±0.36	8.96±0.05	6.29±0.04	1.42±0.01	Wet relax cV% of Kp=8.57
M-TF	55.81±0.35	9.35±0.04	5.96±0.03	1.56±0.01	
H-TF	50.92±0.38	9.27±0.06	5.49±0.02	1.68±0.01	
L-TF	59.76±0.53	9.23±0.06	6.47±0.03	1.42±0.01	Full relax cV% of Kp=5.36
M-TF	60.21±0.04	9.59±0.04	6.27±0.02	1.52±0.01	
H-TF	57.86±0.41	9.57±0.05	6.04±0.01	1.58±0.01	
L-TF	60.64±0.36	9.45±0.03	6.41±0.02	1.47±0.01	W1 cV% of Kp=5.23
M-TF	59.60±0.44	9.56±0.38	6.24±0.04	1.53±0.02	
H-TF	58.38±0.53	9.75±0.03	5.99±0.03	1.63±0.02	
L-TF	60.52±0.33	9.47±0.04	6.38±0.02	1.48±0.01	W3 cV% of Kp=5.42
M-TF	61.00±0.53	9.79±0.05	6.23±0.04	1.57±0.03	
H-TF	58.79±0.54	9.84±0.07	5.97±0.02	1.65±0.01	
L-TF	60.70±0.36	9.50±0.05	6.38±0.02	1.49±0.02	W5 cV% of Kp=5.09
M-TF	61.81±0.49	9.90±0.03	6.24±0.04	1.58±0.03	
H-TF	58.80±0.63	9.78±0.07	5.93±0.03	1.65±0.01	
L-TF	60.96±0.47	9.53±0.05	6.39±0.02	1.49±0.01	W8 cV% of Kp=6.00
M-TF	61.93±0.53	9.90±0.03	6.25±0.04	1.58±0.01	
H-TF	58.79±0.36	9.96±0.04	5.90±0.02	1.68±0.01	
L-TF	61.02±0.43	9.53±0.05	6.40±0.03	1.49±0.01	W10 cV% of Kp= 5.99
M-TF	61.97±0.45	9.92±0.03	6.24±0.04	1.59±0.02	
H-TF	58.83±0.34	9.98±0.04	5.89±0.02	1.69±0.01	

Note: all K-values calculated under 95% significant level

5.4 Spirality variations of weft knitted fabrics under relaxation

During relaxing the weft knitted structures, shape of the stitches changes while reducing the structural spacing and increasing the stitch densities, which make the spirality deformations in the knitted structures. Figure 5 and 6 show the spirality variations of CO-SP and CO single jersey fabrics respectively. According to both figures, spirality deformation in weft knitted single jersey fabrics negatively correlate to fabric tightness. Because, higher fabric tightness makes the more stitch densities and lower structural spacing, which are not allowing the wales to displace from their position during relaxation.

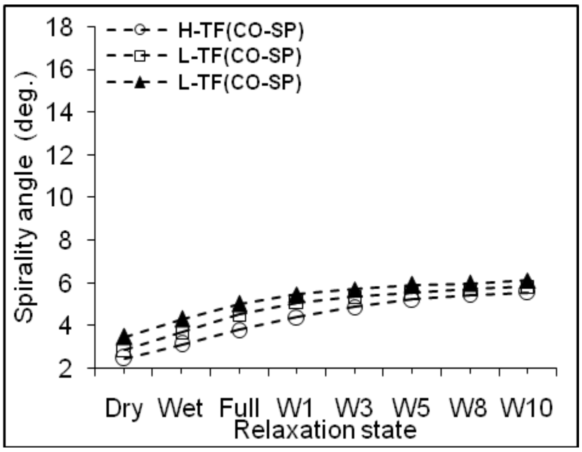


Figure 5 Spirality variations of CO-SP single jersey fabrics

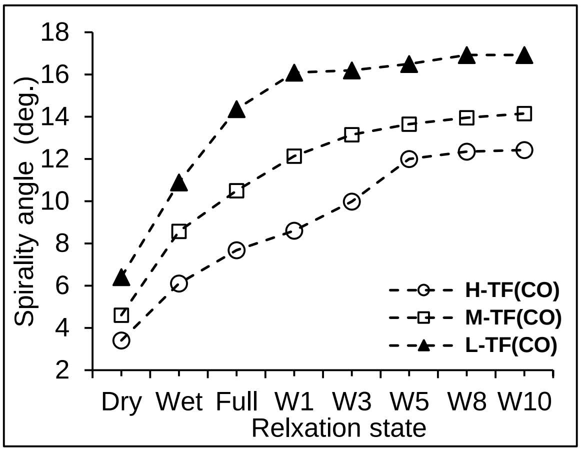


Figure 6 Spirality variations of CO single jersey fabrics

Thus, higher stitch densities may give more inter yarn frictional forces and compression to the wales to reduce the spirality deformations. Hence, spirality deformations increased with the relaxation of knitted structures. This would be that knitted loops are released their internal yarn forces when exert frictional, torsional and flexural forces during knitting to reach to a minimum energy state. This change the knitted loop shape, due to wetting with agitation and providing mechanical and heat energy in wet relax, full relax and also during washing treatments. Thus, it is possible to bend the knitted stitches into 3rd dimension. Ultimately, wale distortions take place due to vigorous washing actions. This leads to increase spirality angle. Similar tendency was reported by some other research works (Higgns *et al.*, 2003,Tao J. *et al.*, 1997 and Anad, *et. al.* 2002).

It is very clearly shows that CO single jersey fabrics given the much higher spirality values compared to that of CO-SP single jersey fabrics, even though both structures were knitted with same stitch lengths. Reason is the higher tightness factors and stitch density values given by CO-SP single jersey fabrics, which were occurred due to good resiliency power of CO/SP yarns. These high fabric tightness and stitch densities can give good inter yarn frictional forces and compressive forces against the wale distortions with making lesser structure spacing during progression of relaxation treatments.

Figure 7 and 8 show the spirality variations of 1x1 rib fabrics. Similar to single jersey fabrics, rib fabrics also showed the negative correlation between spirality and fabric tightness and more spirality deformation with the progression of relaxation treatments. Reasons would be same as for single jersey fabrics as given above.

Acceptable maximum spirality angle for weft knitted structures is considered as 5° in the industry. According to this, CO-SP single jersey fabrics gave the acceptable spirality variations compared to CO single jersey fabrics, even though both the types of single jersey fabrics we knitted using same stitch lengths. Thus our spirality results obtained during relaxation for single jersey fabrics are closer to the experiments done by other researcher with half plated CO and CO-SP single jersey fabrics, but, slightly higher spirality angles were obtained than full plated CO and Spandex single fabrics, which was reported as 1.25° to 1.75° (Marmarali, 2003). According to two figures, it can be observed that spirality angles are negatively correlated to fabric tightness factor.

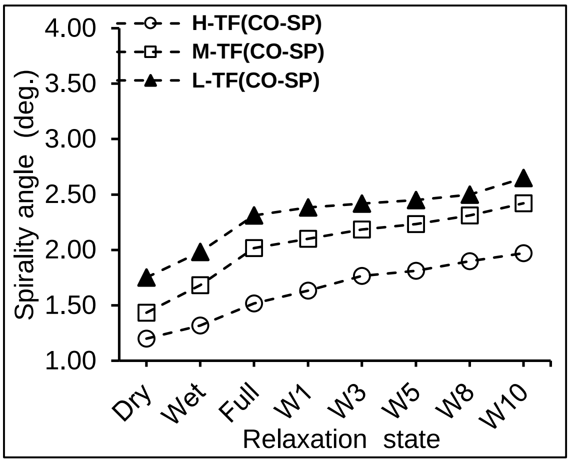


Figure 7 Spirality variations of CO-SP 1x1 rib fabrics

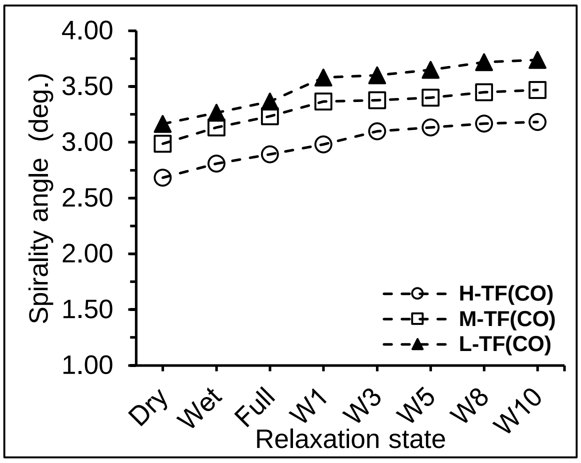


Figure 8 Spirality variations of CO 1x1 rib fabrics

Thus, spirality angle increased with the progression of relaxation treatments due to changing the stitch shapes while being relaxing them. These behaviors are same as in single jersey fabrics. However, CO-SP rib fabrics showed much lower spirality deformation angles than CO rib fabrics due to the their higher stitch densities and lower structural spacing, which may develop higher inter yarn frictional forces and compressive forces acting on wales, than in the case CO rib fabrics. Thus, it is important to note that both CO-SP and CO 1x1 rib structures showed the spirality angles lesser than 5°, which is the industry acceptable limit for spirality angle. Compared to single jersey fabrics, 1x1 rib fabrics showed very low spirality angles during each relaxation stage. Two reasons can be given for this behavior.

(i) Structural knit cell (SKC) of a 1x1 rib stitch has a straight yarn link part and therefore, rib stitches are made in two planes, which can balance the yarn forces in the knitted stitch, resulting a balanced structure. But, in single jersey structure, after one stitch made, yarn in sinker loop bend into same plane with increasing yarn forces, resulting an imbalance plain structure. Unlikely, structures like rib structures can well balance the forces acting on its' stitch during wetting and vigorous relaxation procedures. Therefore, wale displacements are lower during relaxation the rib stitches.

(ii) Rib structures show higher fabric tightness factor values than single jersey structures and make higher stitch densities with lower structural spacing. This also affects to lesser spirality values of rib structures compared to single jersey structures.

Thus, according to the literature survey, it was found that yarn twist can give a significant effect on spirality. As given in Table 1, CO-SP yarns had the higher twist than CO yarns and therefore, structures made from CO-SP could have higher spirality. But, according to the figures 5-8, CO-SP knitted structures have given lower spirality deformation than CO knitted structures. Reasons could be that the higher resiliency power, higher stitch densities and lower structural spacing may have control the effect given by yarn twist.

Thus, it is expected to give more restrictions such as higher inter yarn frictions, higher compressional forces acting on wales with increasing stitch densities, fabric tightness and reducing structural spacing during the relaxation treatments from dry relax to W10 causing to reduce spirality. But it was not observed by the figures 5-8 and they show the gradually increase the spirality with the treatment. Reasons would be that the effect from restriction forces has overrun by the effect given by changing the stitch shape during relaxation and also it is possible to bend the stitches into 3rd dimension with the treatments causing to displace the wales.

Further, it was established mathematical models for spirality variations of three structures based on single and multiple linear regressions with use of ANOVA (step-wise variable adding) technique, using the data from full relaxation up to 10th machine washing cycle, using SPSS software. Following tables 8-11 give the established models and the respective ANOVA summary, which has given for the model having highest correlation coefficients (R^2). ANOVA technique was used under 95% significant level. For establishing the correlation models, TF have calculated using the following formula (5),

$$\frac{\sqrt{tex}}{stitchlength};(tex^{1/2}\ cm^{-1}) \qquad (5)$$

Table 8 Single and multiple linear regression models for spirality angle of CO-SP single jersey fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 10.197-0.264TF	0.084	0.1750
2	Kp	Y = 23.969-10.065Kp	0.302	0.066
3	Ks	Y = -8.882+0.317Ks	<0.0001	0.7170
4	TF , Kp	Y = 36.931-0.31TF-13.951Kp	0.0710	0.2970
5	TF , Ks	Y = -7.172-0.058TF+0.303Ks	<0.0001	0.7240

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	-7.172	3.559	0	-2.015	0.062	19.7
TF	-0.058	0.094	-0.093	-0.625	0.541	
Ks	0.303	0.056	0.809	5.457	0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 9 Establishment of single and multiple linear regression models for spirality angle of CO single jersey fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 66.634-2.99TF	0.0001	0.606
2	Kp	Y = 73.39-39.568Kp	0.0910	0.168
3	Ks	Y = 2.061+0.441Ks	0.5210	0.026
4	TF , Kp	Y = 13.167-4.771TF+56.04Kp	0.0004	0.7290
5	TF , Ks	Y = 42.778-4.047TF+1.704Ks	<0.0001	0.9220

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5thregression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	42.778	5.828	0	7.340	0.0001	97.8
TF	-4.047	0.308	-1.054	-	<0.0001	
Ks	1.704	0.219	0.626	7.793	0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 10 Establishment of single and multiple linear regression models for spirality angle of CO-SP 1x1 rib fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 6.508-0.228TF	<0.0001	0.7230
2	Kp	Y = 7.069-2.176Kp	0.227	0.0900
3	Ks	Y = -2.364+0.045Ks	<0.0001	0.8500
4	TF , Kp	Y = 3.084-0.265TF+1.824Kp	<0.0001	0.7670
5	TF , Ks	Y = -1.288-0.03TF+0.04ks	<0.0001	0.85200

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	-1.288	2.218	0	-0.581	0.570	43.2
TF	-0.03	0.061	-0.113	-0.497	0.626	
Ks	0.04	0.011	0.820	3.613	0.003	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 11 Establishment of single and multiple linear regression models for spirality angle of CO 1x1 rib fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 8.467-0.285TF	<0.0001	0.8210
2	Kp	Y = 8.667-3.459Kp	0.0002	0.5980
3	KS	Y = -10.44+0.228Ks	<0.0001	0.7010
4	TF , Kp	Y = 6.525-0.688TF+5.943Kp	<0.0001	0.9520
5	TF , Ks	Y = -0.124-0.197TF+0.166Ks	<0.0001	0.9240

Note: TF: tightness factor; Y: spirality

ANOVA summary of 4th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\lvert t \rvert$	F value
Intercept	6.525	0.446	0	14.6	0.0001	147.5
TF	-0.688	0.066	-2.184	10.4	<0.0001	
Kp	5.943	0.933	1.328	6.37	<0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

According to the ANOVA analysis, CO-SP single jersey and 1x1 rib structures and CO single jersey structures have shown the good correlation models, which have the R^2>72%. All these structures have shown the significant effect collectively from fabric tightness factor (TF) and stitch density constant (Ks) or stitch shape factor (Kp) on their spirality deformations.

6 CONCLUSIONS

During dry-, wet-and full-relaxation treatments further in washing treatments, weft knitted structures are under gone relieving the heavy strains imposed on them and subjected to severe structural changes. Due to this, course and wale densities and stitch densities have changed and these changes have dependent on the fabric tightness.

Structural spacing of CO-SP and CO single jersey and 1x1 rib structures gradually decrease during relaxation of knitted fabric due to increasing the wale and course densities. In both types of knitted structures made from CO-SP and CO, structural spacing were proportionate to TF^{-1} and lower structural spacing give the lower spirality deformations. Compared to CO structures, CO-SP single jersey and 1x1 rib structures give higher wale and course densities with lower structural spacing. In addition, higher WPC^{-1} given by CO-SP and CO single jersey structures than their CPC^{-1}. However, an opposite behavior shows by CO-SP and CO 1x1 rib fabrics.

Higher stitch densities show by CO-SP single jersey and 1x1 rib structures than their CO structures and it is proportionate to TF. Stitch density increase with relaxation level, which causes to reduce the dimensional deformation and increase the dimensional stability. Dimensional constants change with the relaxation level and higher values given by CO-SP structures than CO structures, even though they made with same stitch lengths. CO-SP single jersey and 1x1 rib structures can become to a stable state faster than CO structures.

Spirality deformations are lower with CO-SP single jersey and 1x1 rib structures compared to same CO knitted structures and they proportionate to TF^{-1}. Both CO-SP and CO rib structures can give very much lower spirality deformations compared to single jersey structures. In spite of the effects given by the higher stitch densities, fabric tightness and lower structural spacing resulting from the progression of relaxation treatments, spirality deformation can also increase continuously during washing treatment of the garments.

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